Determining the Fast Neutron Energy Response Characteristics of Fermilab Instrumentation

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Introduction:

Several 'documented' tests have been performed, to determine the neutron response of Fermilab instrumentation. Most of these tests were single source and/or instrument specific[1,2,3,4]. In 1988, however, a selection of instruments was exposed to all the neutron source types controlled by the Safety Section. The resultant data, at first look, appears extremely useful. However, only the instruments' response to the mixed neutron-photon flux emitted from each source was determined. The photon component is taken as part of the measurement, and in some cases, is quite large. Only three instruments yielded acceptable information on the neutron energy response alone, the photon insensitive REM-402 and AN/PDR-70 (SNOOPY),and the DoDo (using a Ag decay technique[5])

An attempt to characterize the neutron response of any detector in a mixed field must include the reliable subtraction of the photon component. A suitable, relatively neutron insensitive detector must be found. Attix[6] refers to a high Z shielded (energy compensated) GM counter or Mg-Ar ion chamber as being suitable for this application since both have low neutron/photon response ratios. Fermilab's Safety Section possesses energy compensated GM detectors (Amperex ZP1301) and an Al-Ar ion chamber. As aluminum and magnesium have comparable cross-sections for neutrons in the range of 0.5 to 10 Mev (total cross section of approximately 2-3 Barns[7]), the Al-Ar chamber is a suitable substitute for one fabricated of Mg-Ar.

Photon Response:

The proper subtraction of photon dose measured by one detector directly from the neutron + photon dose of another detector, requires that the photon energy responses of both detectors be equivalent. Thus the photon energy dependence of both detectors must be determined and effectively equalized prior to photon dose subtraction.

Although Attix[6] recommends the photon detector types used in this study, it is nonetheless desirable to determine their response to neutrons and to show their relative neutron insensitivity. This can be accomplished by:

1. Comparing the photon dose rate, if known, (from a neutron source emitting a photon spectrum in the region of uniform response of the test detectors) to the dose measured by these detectors;

2. Comparing the detectors' response to the response of acceptable detectors previously used for comparable measurements; and

3. Measuring the high voltage source plateau saturation curves of the N + γ and γ-only detectors with both neutron and photon detectors. Due to the relatively dense ionization tracks from protons created by neutron elastic scattering events within a neutron sensitive detector, recombination losses are more prevalent, and will be manifested by a long plateau 'knee' relative to the photon plateau. A neutron insensitive detector will have identical photon and neutron source plateaus.

In connection with point 1 above, photon detector measurements were performed with a ^{252}Cf neutron source. These yield photon exposure rate data comparable to the calculated photon dose rate. Specifically, the Al-Ar chamber data yields 0.630 mrad/hr and the ZP1301 data 0.694 mrad/hr, compared to 0.618 mrad/hr calculated for the Cf252-7.2-1 source[8] using ISO/DIS 8529[9].

In connection with point 2 above, photon detector measurements were performed with a PuBe neutron source. These yield photon exposure rate data comparable to that obtained from a DOE-Battelle supplied detector used in a DOE Radiological Calibrations Intercomparison Program[10]. Specifically, the Al-Ar chamber data yields 0.571 mrad/hr and the ZP1301 data 0.556 mrad/hr, compared to a measured dose rate from the 238Be-7.2-1 of 0.55 mrad/hr obtained in the intercomparison program.

In connection with point 3 above, high voltage saturation curves were measured for the Al-Ar chamber. The chamber's response to both ^{60}Co and PuBe sources as a function of high voltage is shown in Figure 1. These results are compared in Figure 2 to similar measurements performed in 1978 for a prototype Chipmunk (1055) chamber. Note the longer 'knee' present on the PuBe source plateau curve, for the neutron-sensitive Chipmunk chamber, compared to the ^{137}Cs plateau. The relative neutron insensitivity of the Al-Ar chamber is revealed by the virtually identical PuBe and ^{60}Co plateau curves shown in Figure 1.

Photon energy dependence measurements were performed on all detectors used in the April 1990 tests: A 1055 ion chamber, the Al-Ar ion chamber, and a ZP1301 GM detector. The resultant responses are shown in Figure 3. While the responses are similar above ~0.4 Mev, considerable differences exist at lower energies. In particular, the differences between the Chipmunk's response and that of the Al-Ar chamber lead to an apparent over-subtraction of the photon component when the Al-Ar chamber is used to correct for the γ-ray contribution to the Chipmunk response when neutron sources (which emit low-energy photons as well) are used.

A technique of attenuating the low energy portion of the photon spectrum with 1/16" Pb source shield was tried[9,11]. Figure 4 shows the photon energy dependence of the three detectors when a 1/16" thick Pb shield was placed over each of the γ-ray sources. As seen, the response as a function of photon energy is almost identical for each detector, since the low energy γ-rays which contributed to the lack of equivalence have been essentially removed by attenuation in the Pb. This method of attenuating the low energy portion of the neutron source photon emission was then adopted for use in determining the neutron response of the Chipmunk (1055) chamber.

Neutron Response:

Measurements of the mixed neutron-photon fields from PuLi, PuF, Cf, PuBe, and AmBe were performed with all three detectors with and without the Pb source shields. The neutron source photon measurement data from the ZP1301 GM detector and Al-Ar chamber was subtracted from the corresponding mixed neutron-photon measurement data from the 1055 chamber. Each resulting neutron dose rate data point was normalized to the calculated neutron dose (decay and distance corrected, from the manufacturer's or NBS equivalent calibration).[8]

$$\text{Neutron Response}_{1055} = \frac{(N + \gamma)_{1055} - \gamma_{detector}}{\text{True N-Dose}}$$

The resultant fast neutron spectral response of the 1055 chamber, based on the use of Pb shielded sources, are displayed in Figures 5 and 6. As can be seen, both photon subtraction methods yield comparably close results.

Since the photon energy dependence of the ZP1301 GM detector and 1055 chamber are close (Figure 3), a response curve based on the use of unshielded sources for this combination was also determined for comparison (Figure 7). It differs from the responses of Figures 5 and 6 primarily at the PuLi and AmBe data points (both sources appear to have large low energy photon components). Composite neutron response curves for the Chipmunk (1055) chamber using all three methods are shown in Figure 8.

<u>Results from 1988 Data</u>:

The information obtained in the neutron source/instrument tests performed in 1988 can yield some useful information on neutron sensitivity of the mixed-field sensitive instruments. The photon component of the PuF, Cf, and PuBe non-shielded source data (these represent high photon energies), acquired during the April 1990 study with the Al-Ar chamber and ZP1301 GM detector, were corrected for decay and directly subtracted from the study instruments' response to yield a reasonable neutron response to these sources. It must be noted that no photon spectral response studies were performed on these instruments in the 1988 study, and a reasonably flat response in the region of interest is assumed. Therefore this data is considered approximate and insufficient for graphical presentation. It is however, presented for comparison in Table 1 together with the resulting data from the Chipmunk(1055) chamber.

For comparison to the Chipmunk (1055) chamber, the neutron energy response of three instruments yielding acceptable information from the 1988 tests, the REM-402, SNOOPY, and DoDo, are shown in Figures 9, 10, and 12. The manufacturer's stated response[12] of the SNOOPY is shown in Figure 11. Our energy data points represent the average neutron energy of the particular source. The manufacturer's data points are not specifically defined.

The under-response of the REM-402 (Figure 9) is due to a manufacturer's calibration source error. This was discussed with the manufacturer, Far West Technologies and, as a result, the EPROM containing the calibration factors was reprogrammed to reflect the correction. The corrected response (as of 4/91) of the REM-402 is shown in Figure 9A.

The DoDo and the Albatross over-response (Table 1 and Figure 12) is a designed-in condition to account for the differing response to the PuBe neutron calibration source flux and the expected energies in accelerator areas. This is discussed at length in references 1 and 2.

Results from 1990 Data:

Comparison of the 1055 chamber data with the new Chipmunk and Scarecrow (1988) data raises an immediate question, as both instruments utilize the 1055 chamber. The 1055 chamber data was acquired by comparing response to absorbed dose (mrad), whereas the Chipmunk and Scarecrow data compares the calibrated response of the complete instrument (mixed field QF=5 for Chipmunk, QF=4 for Scarecrow) to the tissue dose equivalent (mrem) from the appropriate source (QF=7.9 to 10.9). Thus, for comparison, Chipmunk and Scarecrow 'instrument' responses based on the April 1990 1055 chamber data are illustrated in Figure 13 and listed in Table 1. The Chipmunk appears to under-respond by a factor of 1.6 to 1.9, for fast neutron energies. The Chipmunk quality factor (QF=5) was determined for neutron energies present outside of iron and soil shields (apparently based on the results of TM-266[13]), not for the flux from neutron calibration sources.

Scatter:

The April 1990 tests were performed inside the Site 68 building (1st floor). The time available did not allow for a scatter study, however a single neutron source scatter study was performed in 1984 as part of RP Note 48[3]. Comparison of this data (outside 'free air' measurements) with the April 1990 data reveals an approximately 8% increase in the response of Chipmunk/Scarecrow instruments in a PuBe field due to neutron scatter for the

April 1990 geometry. As this information is available for only one data point, no neutron spectral response correction was attempted.

Conclusion:

The technique demonstrated in this note, for the 1055 Chipmunk/Scarecrow chamber, may be used successfully for any of our neutron sensitive instruments. In general: The neutron response of an instrument or detector sensitive to mixed fields can be determined reasonably well by subtracting the photon dose, determined by neutron insensitive detectors, as long as the photon energies are restricted to the spectral region where all detector responses are equal.

Credits:

Gratitude is expressed to several colleagues: to C. Salsbury and J. Larson for their review and comments, and to A. Elwyn for some much needed editing.

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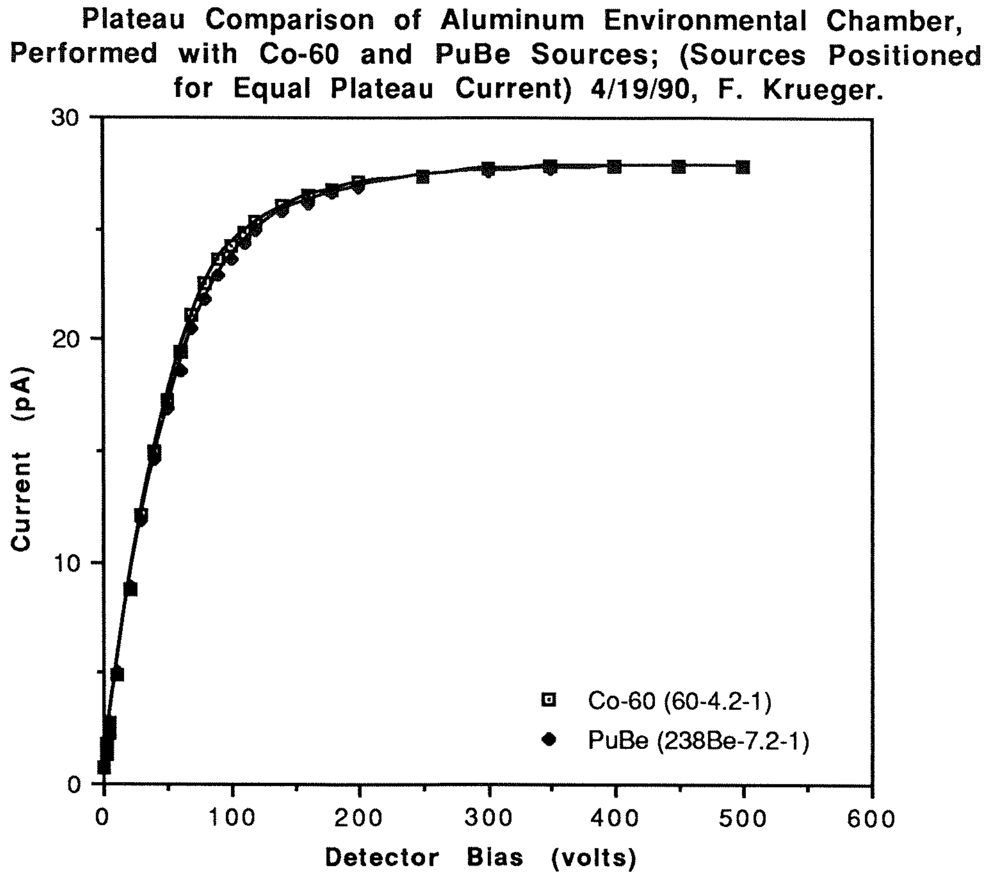


Figure 1

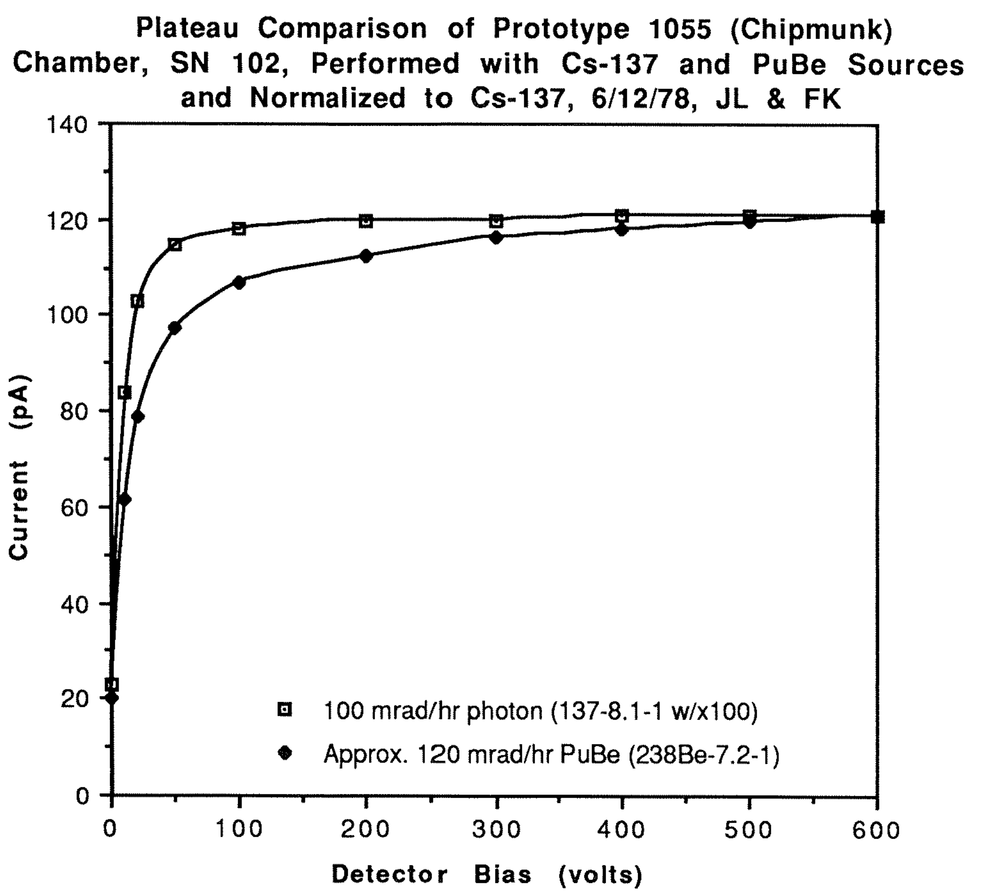


Figure 2

Photon Energy Response of the Detectors used in the Fast Neutron Spectral Response Study, 4/26/90, FK.

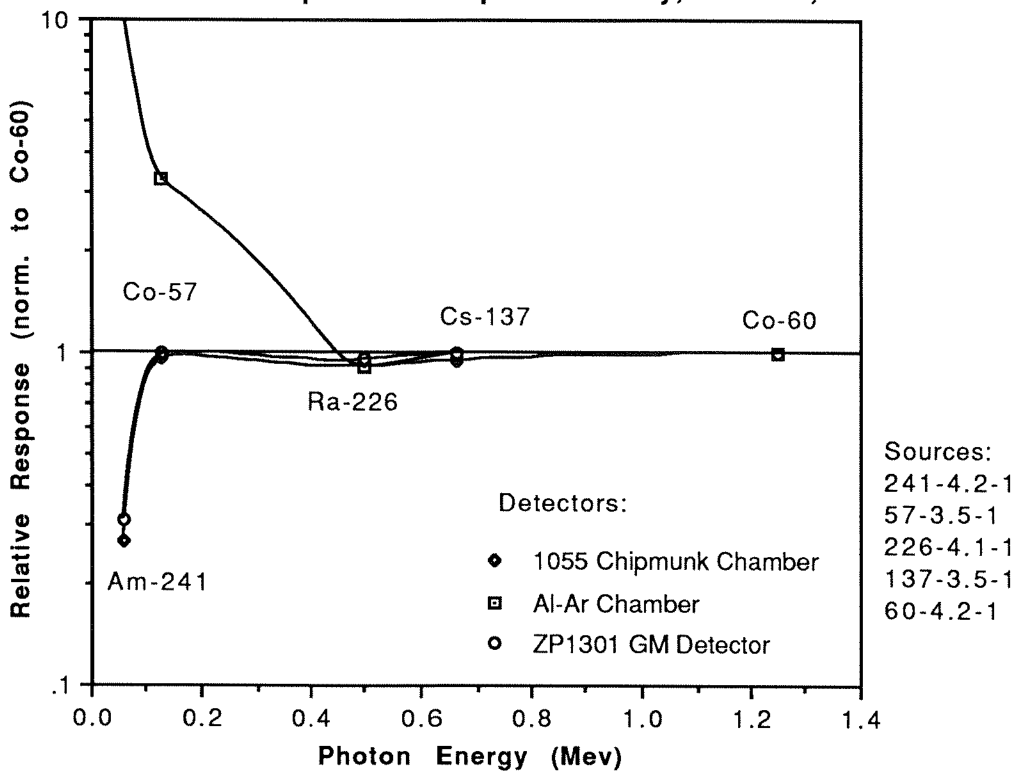


Figure 3

Photon Energy Response of the Detectors (to Pb shielded sources) used in the Fast Neutron Spectral Response Study, 4/26/90, FK.

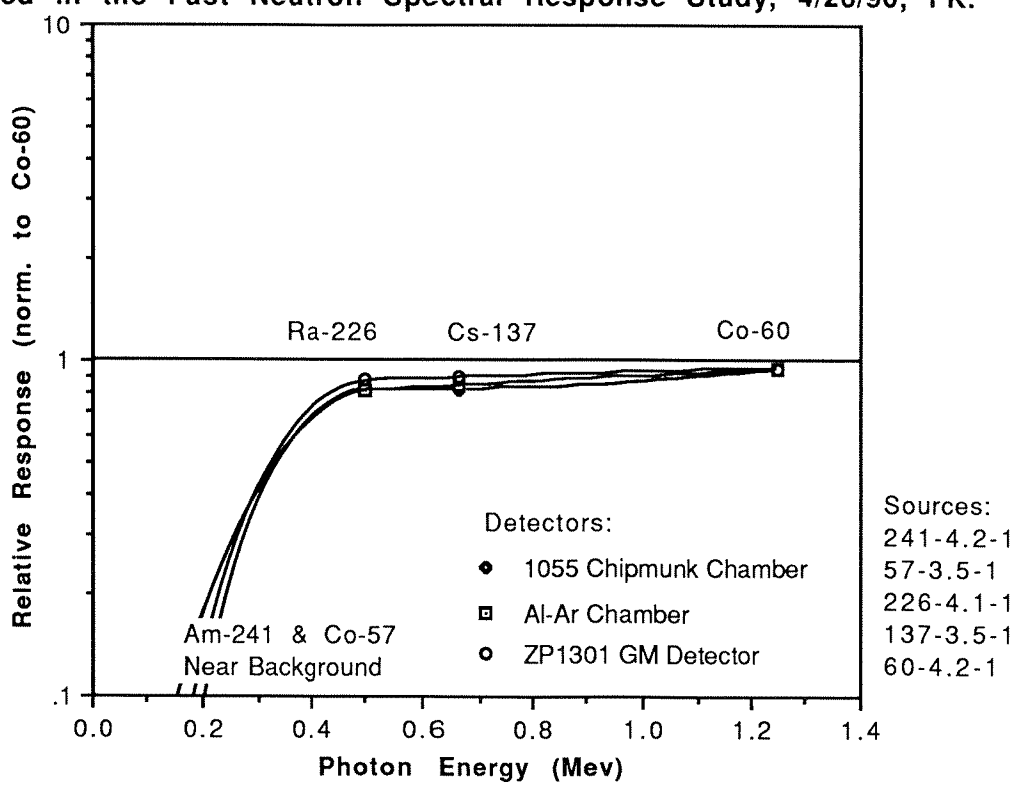


Figure 4

Neutron Energy Response of the Chipmunk (1055) Chamber in Box (steel) to 0.0625"Pb Shielded Sources, using an Al-Ar Ion Chamber to Subtract Photon Dose, 4/26/90, FK

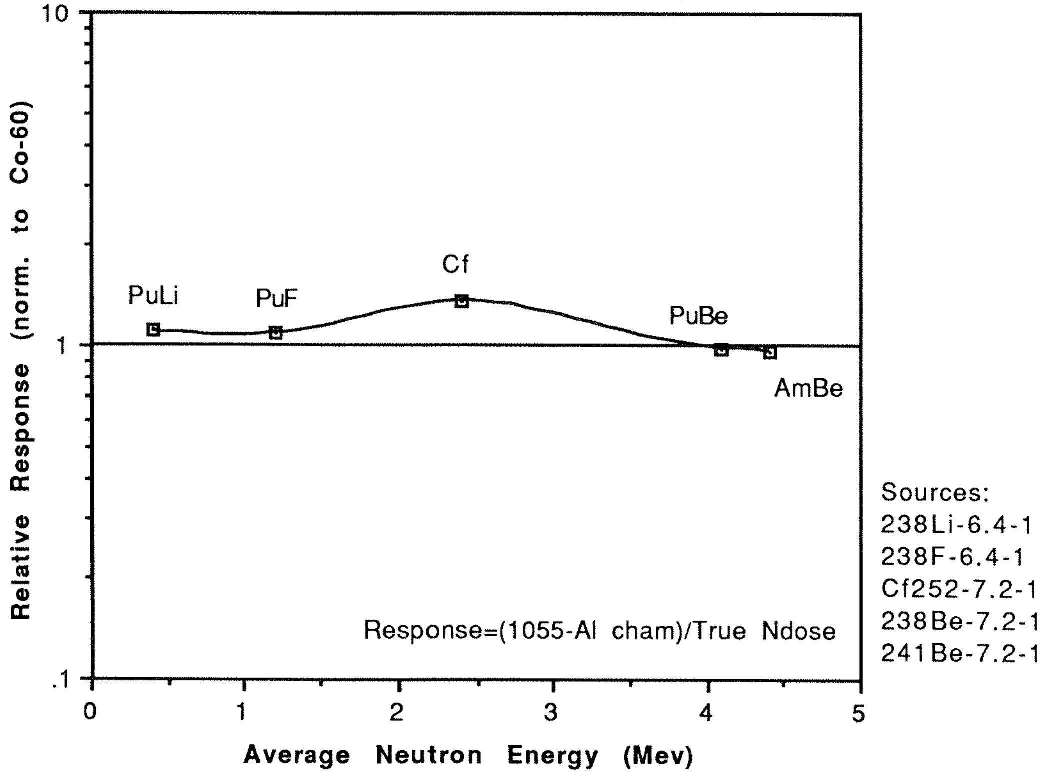


Figure 5

Neutron Energy Response of the Chipmunk (1055) Chamber in Box (steel) to 0.0625"Pb Shielded Sources, using a ZP1301 GM Detector to Subtract Photon Dose, 5/2/90, FK

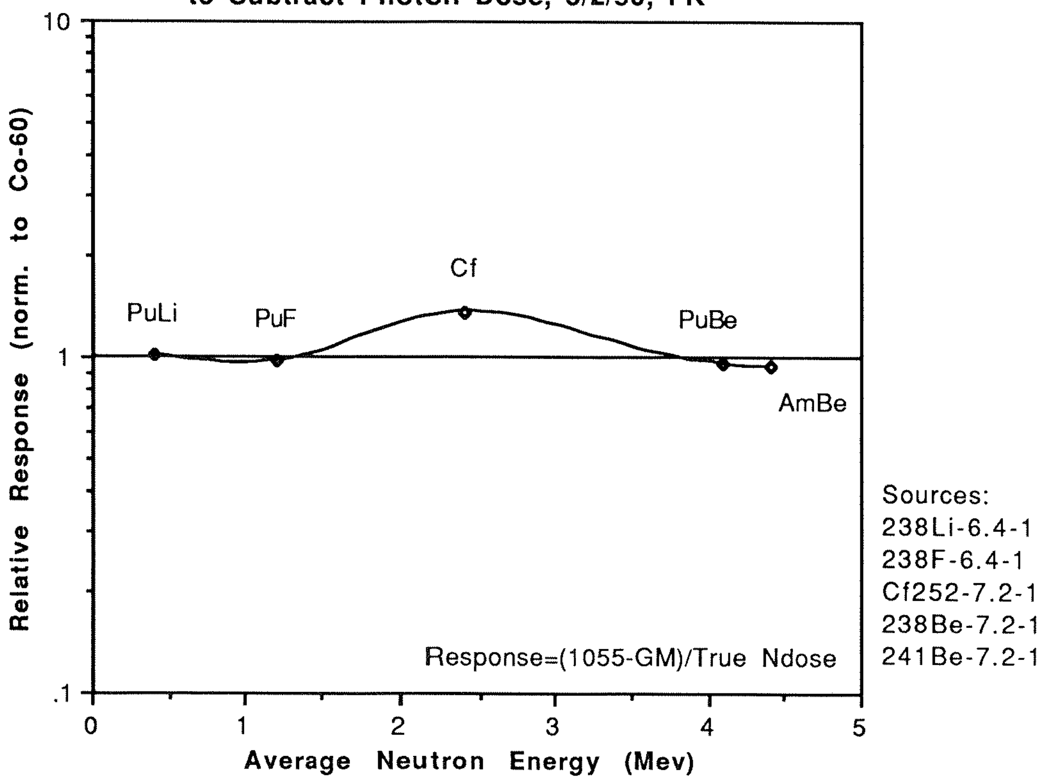


Figure 6

Neutron Energy Response of the Chipmunk (1055) Chamber in Box (steel) to Unshielded Sources, using a ZP1301 GM Detector to Subtract Photon Dose 5/2/90, FK

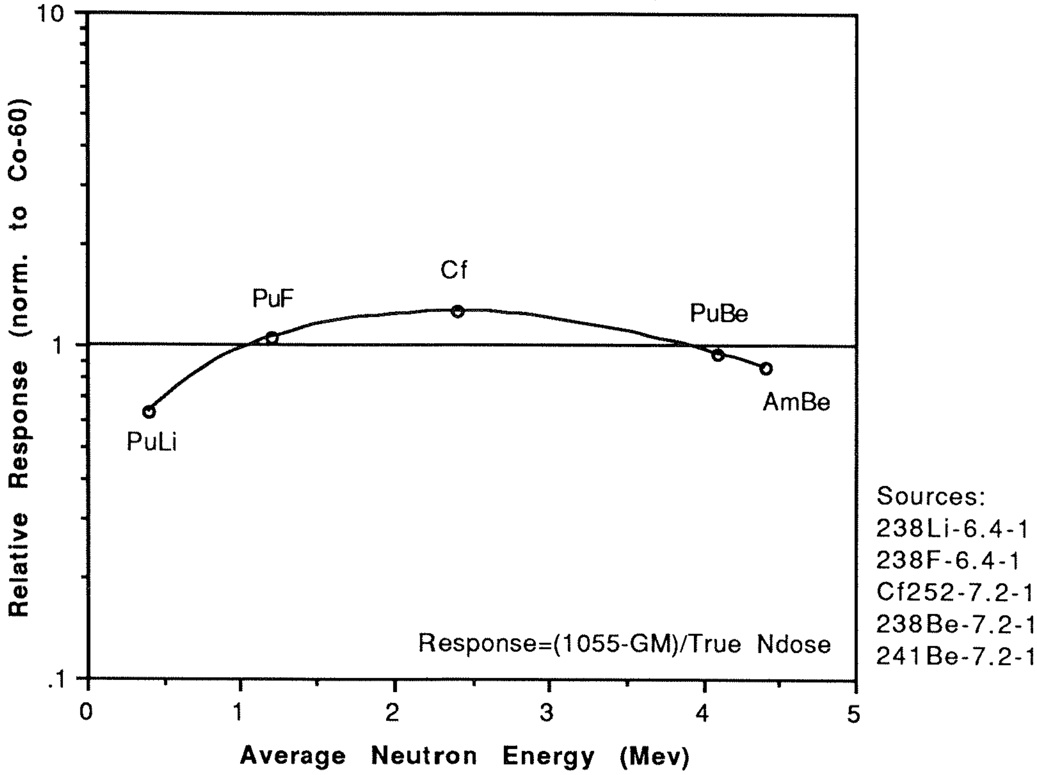


Figure 7

Neutron Energy Response of the Chipmunk (1055) Chamber in Box (steel), 5/2/90, FK

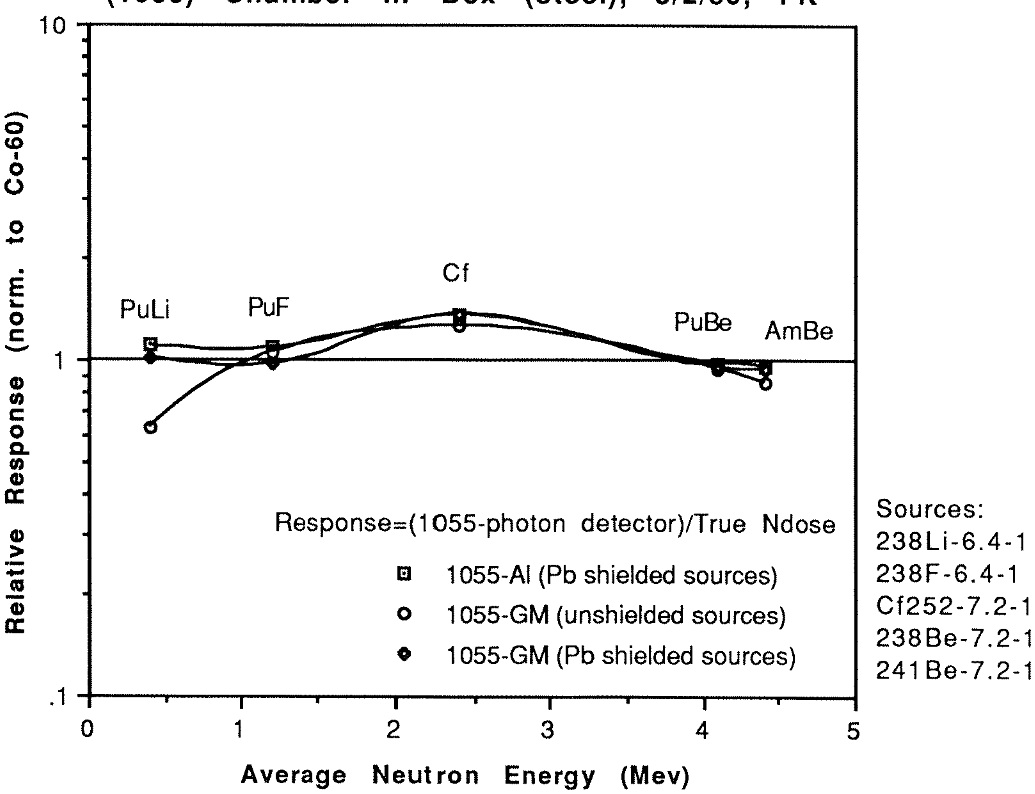


Figure 8

Neutron Energy Response of the Far West Technologies
REM-402 Survey Meter, Normalized to Calculated
True Dose, 4/27/90, from 9/7/88 Data, FK

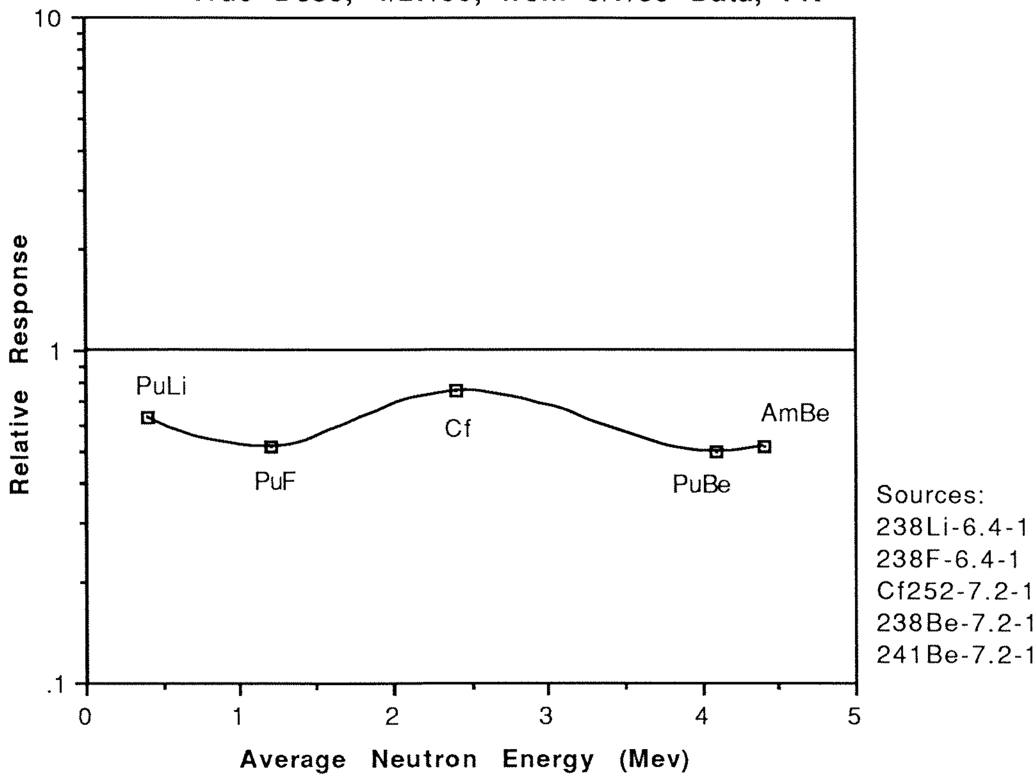


Figure 9

Neutron Energy Response of the Far West Technologies
REM-402 Survey Meter, Normalized to Calculated
Calculated True Dose Rate, 4/2/91, FK

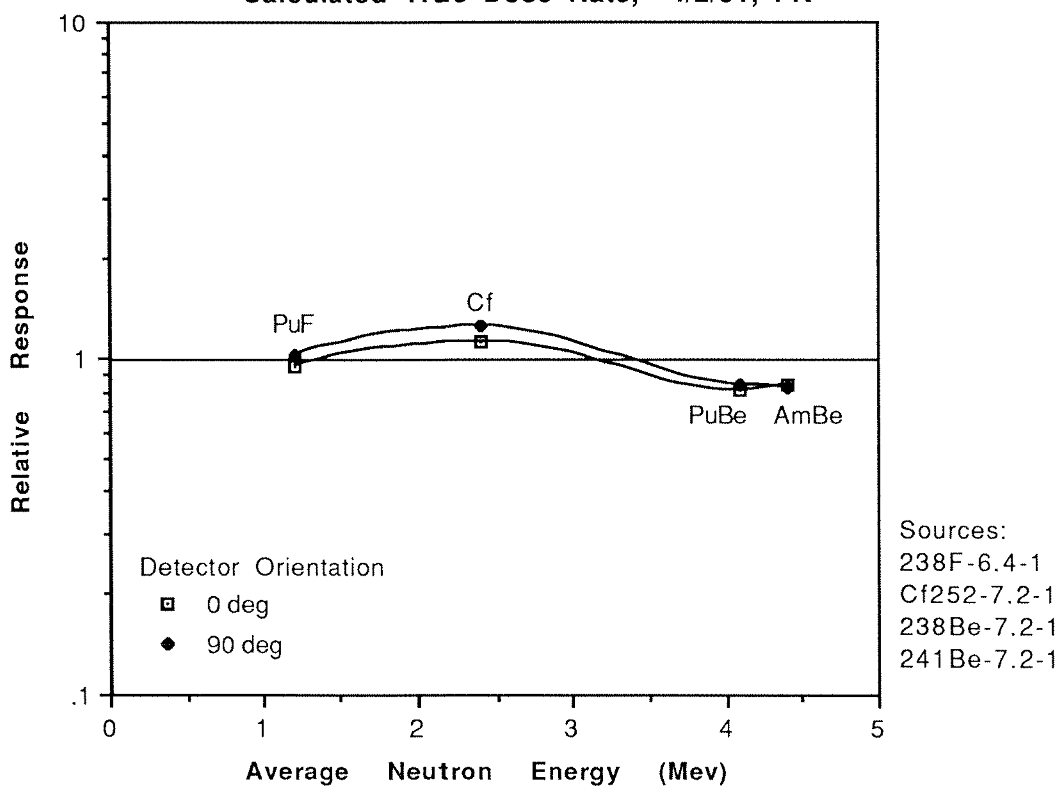


Figure 9A

Neutron Energy Response of the AN/PDR-70 (SNOOPY) Survey Meter, Normalized to Calculated True Dose, 4/27/90, from 9/7/88 Data, FK

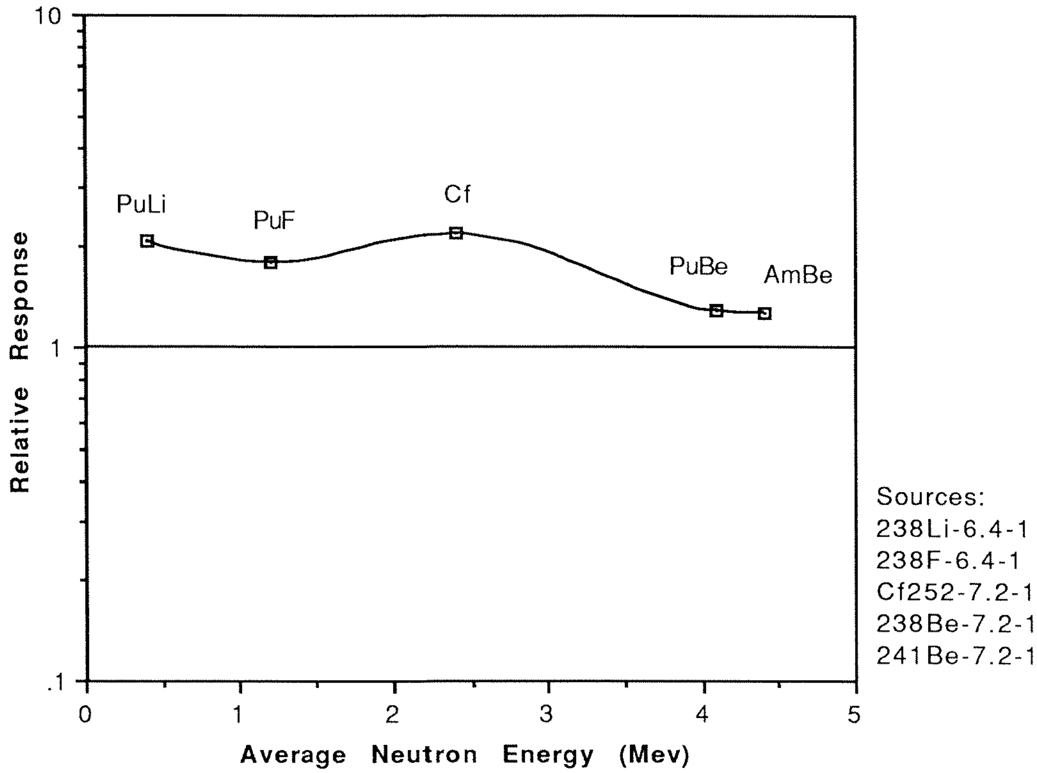


Figure 10

Neutron Energy Response of the AN/PDR-70 (SNOOPY) Survey Meter, extracted in part from NAVSHIPS 0967-871-5220, 5/14/90, FK

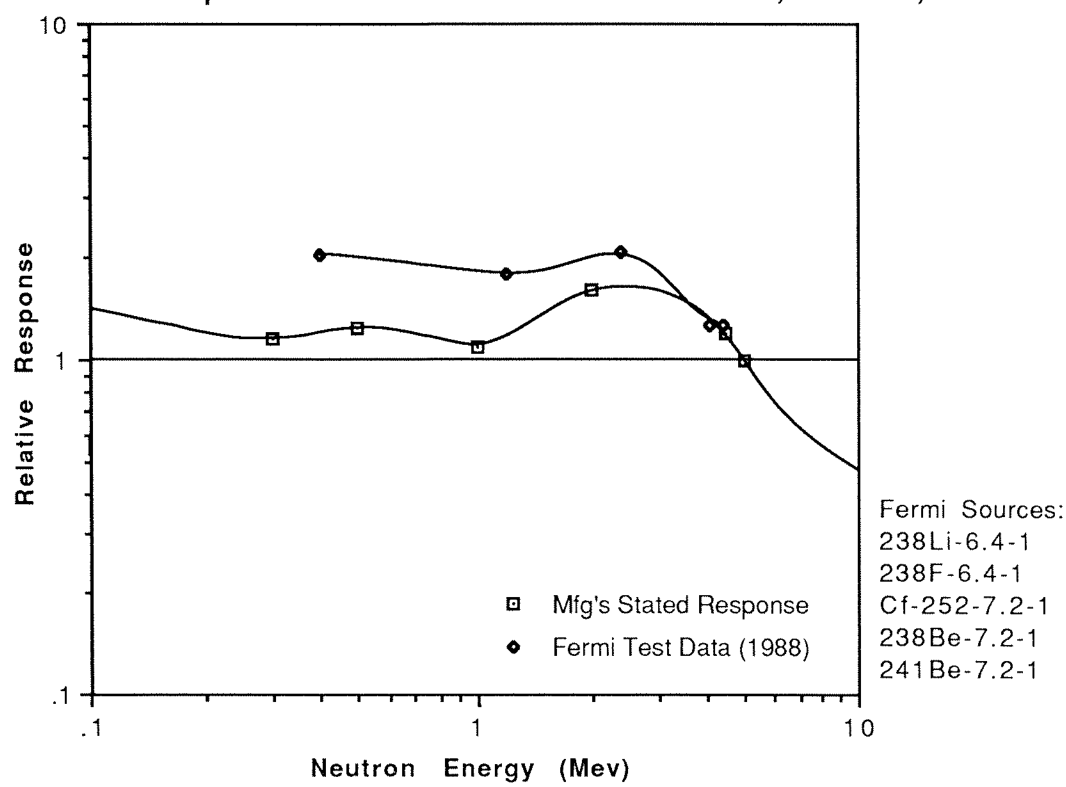


Figure 11

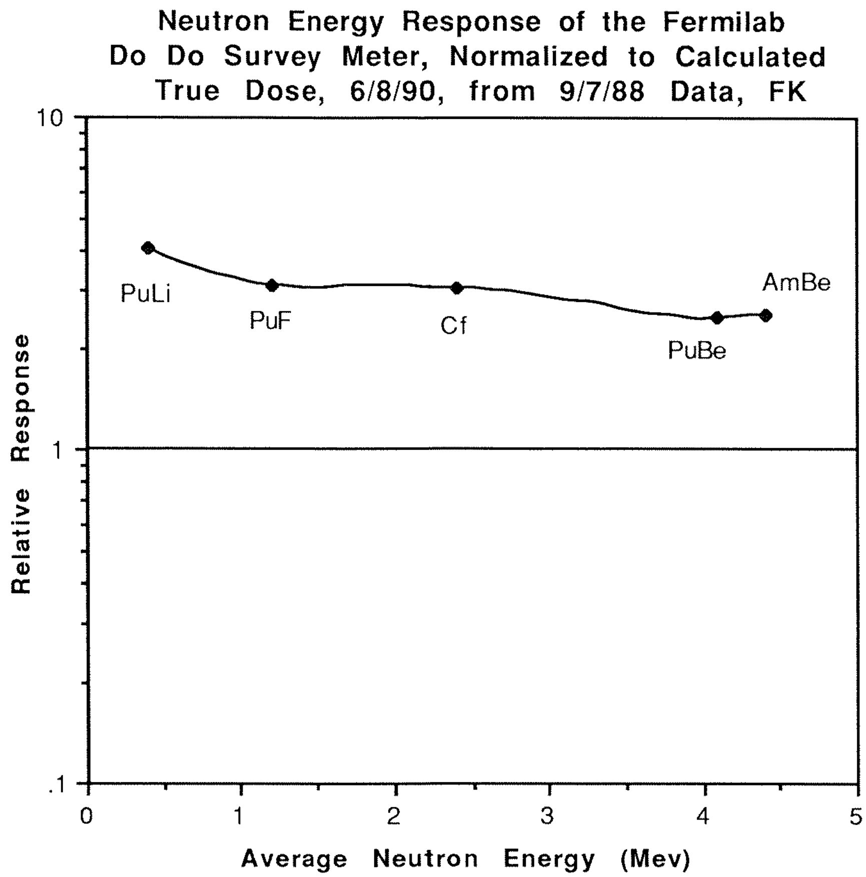
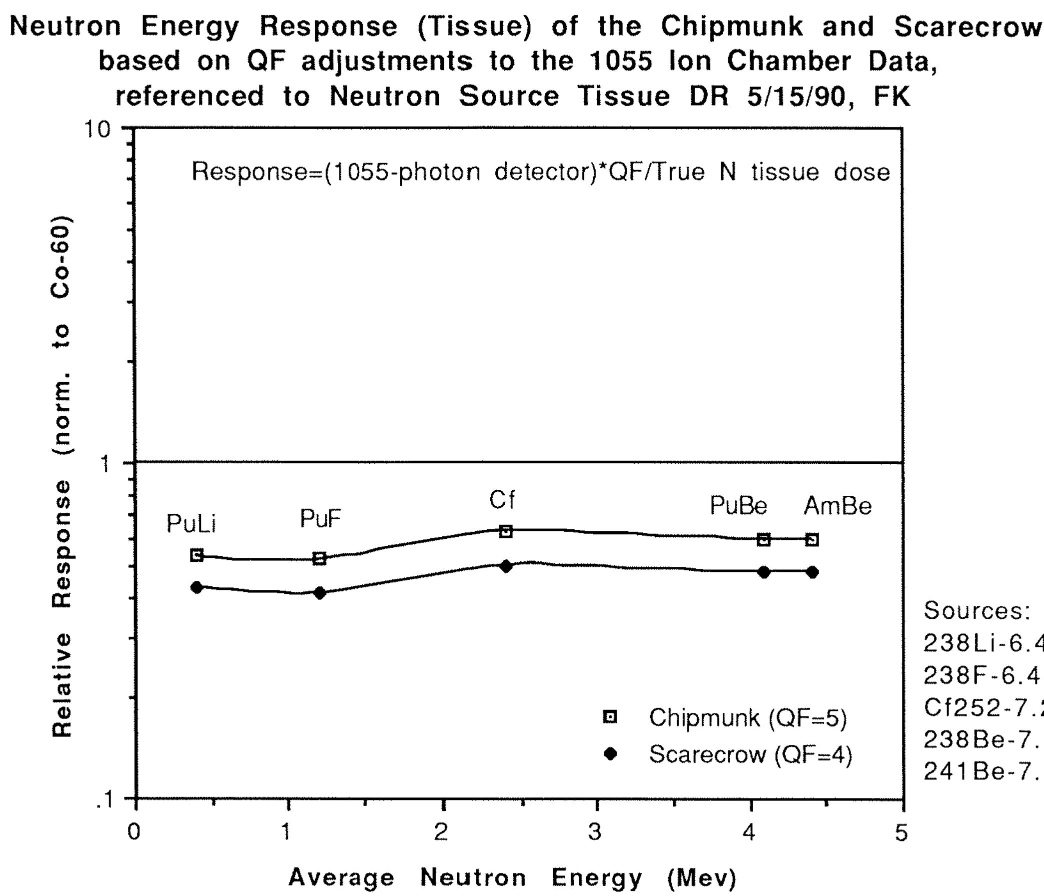


Figure 12



Sources:
238Li-6.4-1
238F-6.4-1
Cf252-7.2-1
238Be-7.2-1
241Be-7.2-1

Figure 13

Table 1

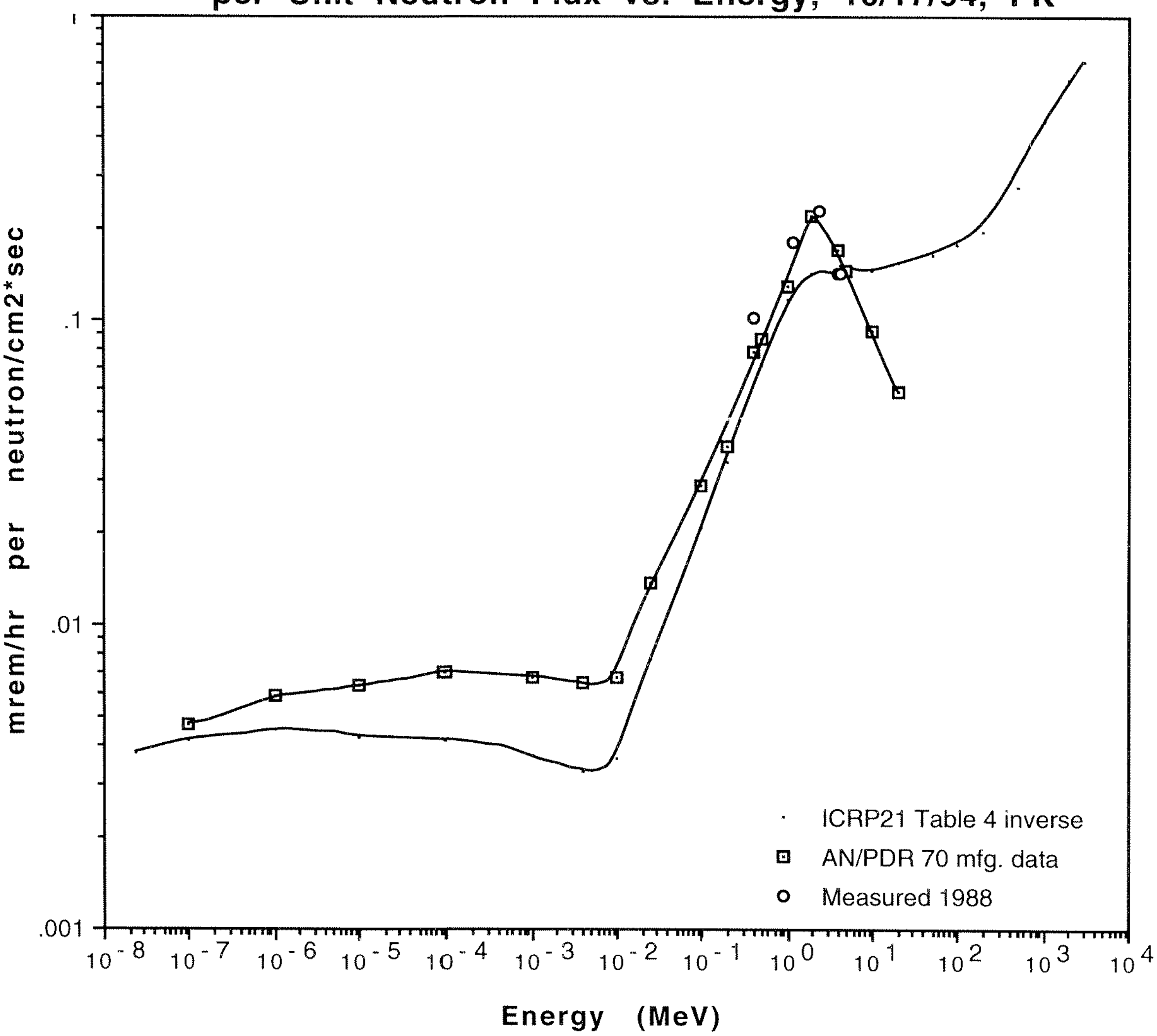
Source	Average Neutron Energy (Mev)	Relative Response						
		Chip. Chamber 1055 test ave.	New Chipmunk 1055 derived	New Scarecrow 1055 derived	Snoopy (1988 Data)	REM-402 (1991 Data)	*Do Do (1988 Data)	TEIR (1988 Data)
Pu238Li-6.4-1	0.4	1.06	0.53	0.43	2.07		4.03	
Pu238F-6.4-1	1.2	1.03	0.52	0.41	1.79	0.96	3.14	0.71
Cf252-7.2-1	2.4	1.37	0.63	0.50	2.08	1.13	3.08	0.75
Pu238Be-7.2-1	4.1	0.97	0.60	0.48	1.28	0.81	2.49	1.01
Am241Be-7.2-1	4.4	0.96	0.60	0.48	1.28	0.84	2.57	

Source	Average Neutron Energy (Mev)	Relative Response						
		HPI 1010 (1988 Data)	Cutie Pie (1988 Data)	New Chip (1988 Data)	Old Chip (1988 Data)	New Scare (1988 Data)	Old Scare (1988 Data)	**Albatross (1988 Data)
Pu238Li-6.4-1	0.4							
Pu238F-6.4-1	1.2	0.79	0.05	0.65	0.48	0.41	0.34	2.35
Cf252-7.2-1	2.4	0.32	0.11	0.44	0.39	0.34	0.28	2.32
Pu238Be-7.2-1	4.1	0.82	0.25	0.65	0.76	0.49	0.53	3.06
Am241Be-7.2-1	4.4							

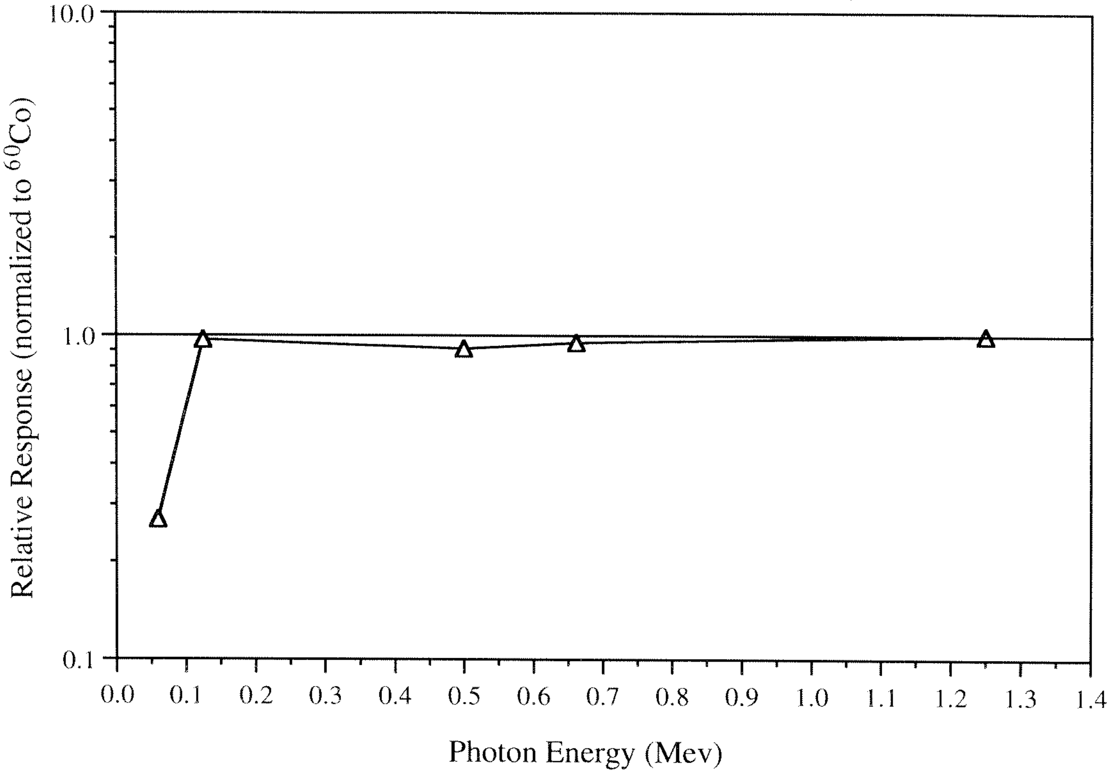
*The DoDo's response was determined using Ag decay techniques (see reference 5).

** The Albatross is calibrated for a correct response to Cs-137 photons, therefore ZP1301 data was simply subtracted.

A Comparison of Tissue Response (ICRP21) and SNOOPY Response per Unit Neutron Flux vs. Energy, 10/17/94, FK



Photon Response of the Chipmunk Ion Chamber
(Far West 1055), in Chamber Box, 1990 Data, FK 5/2/96



Fast Neutron Response of the Chipmunk Ion Chamber
(Far West 1055), in Chamber Box, 1990 Data, FK 5/2/96